REMARKS/ARGUMENTS

This Amendment is responsive to the Office Action of the Examiner mailed January 7, 2004. A request for a two month extension of time accompanies this Amendment.

Claims 9-10 have been rejected under 35 USC 103(a) as being unpatentable over Fermann (US2002/0172486, Fig. 6c particularly) in view of DiGiovanni (US 5,949,941).

In this response, Applicant amends pending claims 9 and 10.

Summary of the Invention

Utilizing amended claim 9, and referring to the exemplary polygon profile having equal interior angles set forth in Fig. 2, the presently claimed invention relates to an improvement in a process for fabricating an optical fiber. The original process for fabricating an optical fiber includes the steps of providing a core doped with active species. Thereafter, an inner cladding is provided surrounding the core. It is the alteration to the profile of this inner cladding constitutes the improvement to the process.

The original inner cladding has a first polygon profile with equal interior angles with discrete sides adjoining one another at a first set of angles. It has the defect that light can be reflected within the inner cladding about the core doped with active species along paths having local modes which do not intersect the core doped with active species. Finally, there is provided an outer cladding surrounding the inner cladding for the confinement of light within the inner cladding.

The specification is clear about the effect "local modes." Specifically, light is wasted. The light is reflected in circuitous path about the core doped with active species so that it never reaches core. As a result, the light incident upon the inner cladding never takes place in the intended optical amplification. Thus, the inner cladding surrounding the core recited before the improvement step is a defective cross-sectional shape with the local modes. The question become, what can be done to remedy this situation?

The improvement to the process is the answer to the question. The process for fabricating an optical fiber has additional steps added to the shaping process used for the first polygon. The first polygon profile with equal interior angles with equal interior angles of the inner cladding is altered to a second skewed or distorted polygon profile having a second set of angles about the core doped with active species. This second skewed or distorted polygon profile of the inner cladding departs from the first with equal interior angles by having small angular changes to at least two of the angles. This gives the second asymmetric and symmetry-broken polygon a second set of angles with the local modes of reflection within the inner cladding minimized and destroyed. Finally, and to realized the preferred embodiments of Figs 11a and 11b, at least one boundary of the asymmetric and symmetry broken polygon is changed to the shape of an arc. Claim 10 points out that the starting polygon can be a square.

Cladding Operation in Reflecting Light

To show the patentability of the inventions of the applicant, it is helpful to briefly review and compare the disclosed invention with the prior art.

Before the review of double cladding fibers related to the current invention, it is useful to recite some basics about fiber optics and phenomena in optics.

Rule of Reflection

Reflection is the abrupt change in the direction of propagation of a wave that strikes the boundary or interface between two different media. At least some part of the incoming wave remains in the same medium. If an incoming light ray makes an angle θ_i with the normal of a plane tangent to the boundary, then the reflected ray makes an angle θ_r with this normal and lies in the same plane as the incident ray and the normal.

Law of reflection: $|\theta_r| = |\theta_i|$

The reflectivity of a surface material is the fraction of energy of the incoming wave that is reflected by it. The reflectivity of a mirror is close to 1.

Fig. 1 shows the relation of the ray of light which strikes the surface that is called the incident ray, the ray of light which leaves the surface that called the reflected ray, and a normal perpendicular to the surface is imagined at the point of reflection. Fig. 2 shows the same relation in which the reflection surface has a radius. In this situation, the normal always pass the center of the radius.

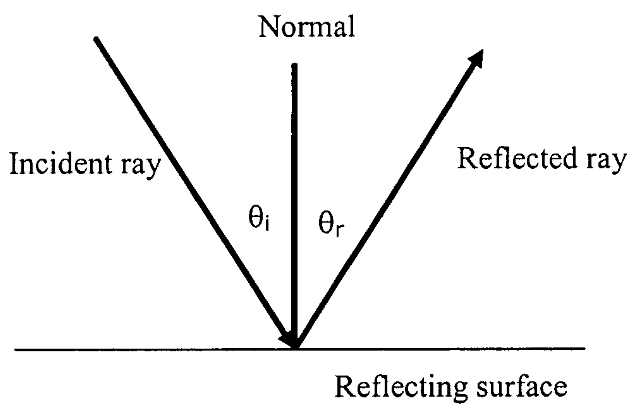


Fig. 1

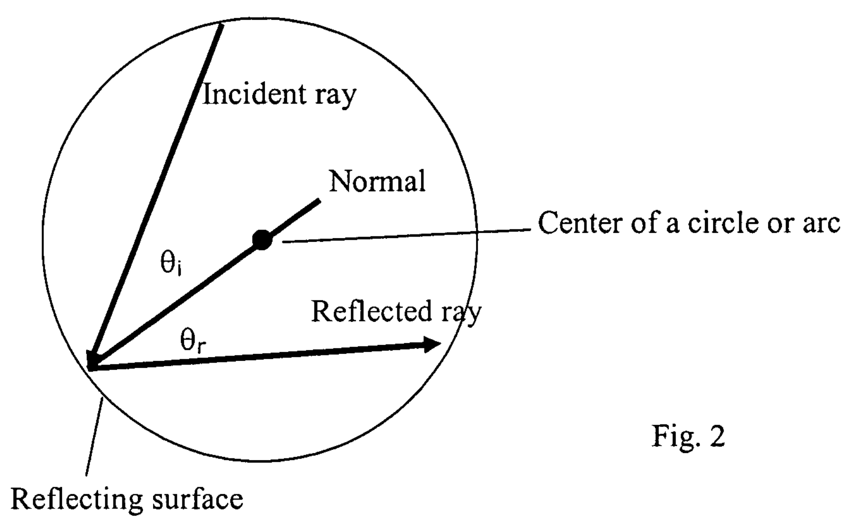
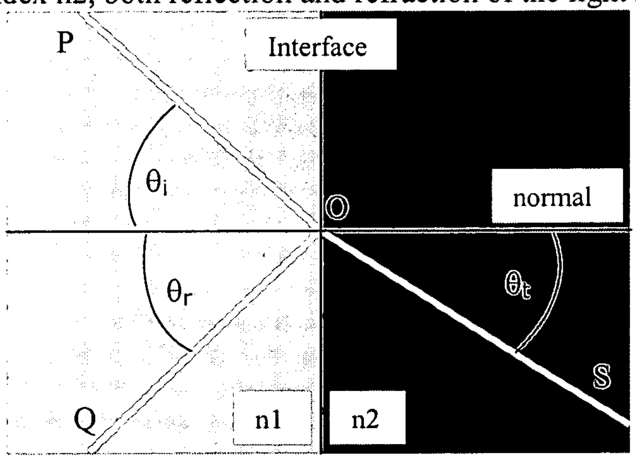


Fig. 2

Based on the rule of reflection, beam direction can be steered by using mirrors.

Total internal reflection

When light moves from a medium of a given refractive index n1 into a second medium with refractive index n2, both reflection and refraction of the light may occur.



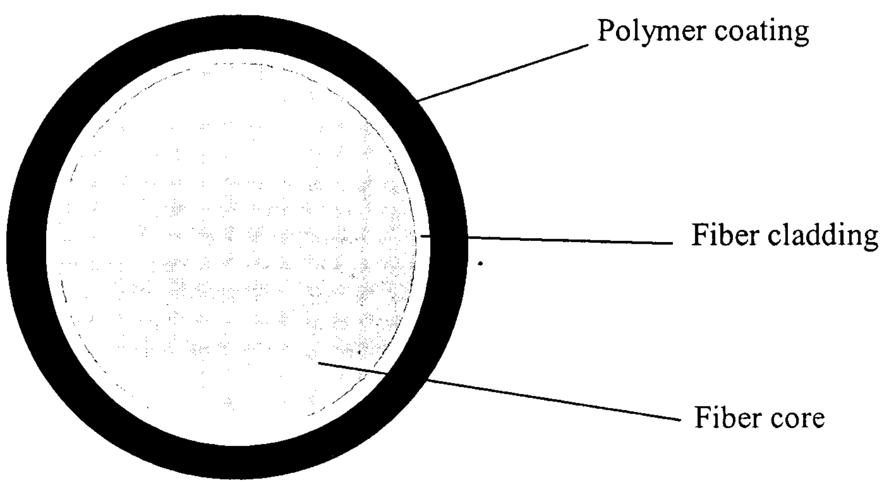
In the diagram above, an incident light ray '*PO*' strikes at point '*O*' of the interface between two media of refractive indexes n1 and n2. Part of the ray is reflected as ray '*OQ*' and part refracted as ray '*OS*'. The angles that the incident, reflected and refracted rays make to the normal of the interface are given as θi, θr and θt, respectively. The relationship between these angles is given by the law of reflection and Snell's law. Fresnel equations can be used to predict how much of the light is reflected, and how much is refracted in a given situation. When moving from a more dense medium into a less dense one (i.e. n1 > n2), above an incidence angle known as the critical angle (θc) all light is reflected. That is, when $\theta_i > \theta$c, Rs=Rp=1. This optical phenomenon is known as total internal reflection. It should be noted that there is no total internal reflection if n1<n2.

Fiber optics and waveguide

It is well known that fiber optics can be used to transmit light. An optical fiber can be seen as a waveguide. Fiber waveguides confine light propagation to a set path which may be straight or curved by taking advantage of total internal reflection. Light must be totally reflected at the interface between the inner and outer materials to be guided along the central passage.

Fig. 3a shows the cross-section of a typical fiber for transmitting light. In Fig. 3a, to create an environment for total internal reflection, it is common that the cladding material has a lower refractive index than the core. The coating (normally plastic materials) is merely for protecting the fiber. Fig. 3b shows the index gradients for two types of fibers. Fig 3c shows the beam transmits through the fiber by total internal reflection. The incident beam with an incident angle θ_{i1} or θ_{i2} over the critical angle to thus transmit through the fiber without coming out from the side of the cladding. If θ_{i1} is smaller than the critical angle, a fraction of the beam will refract and get into the cladding or outer coating. It should be noted that the function of the outer coating is only for protection, while the cladding is only for confining the light inside of the fiber core.

Fig. 3a.



Cross section of a typical fiber for transmitting light

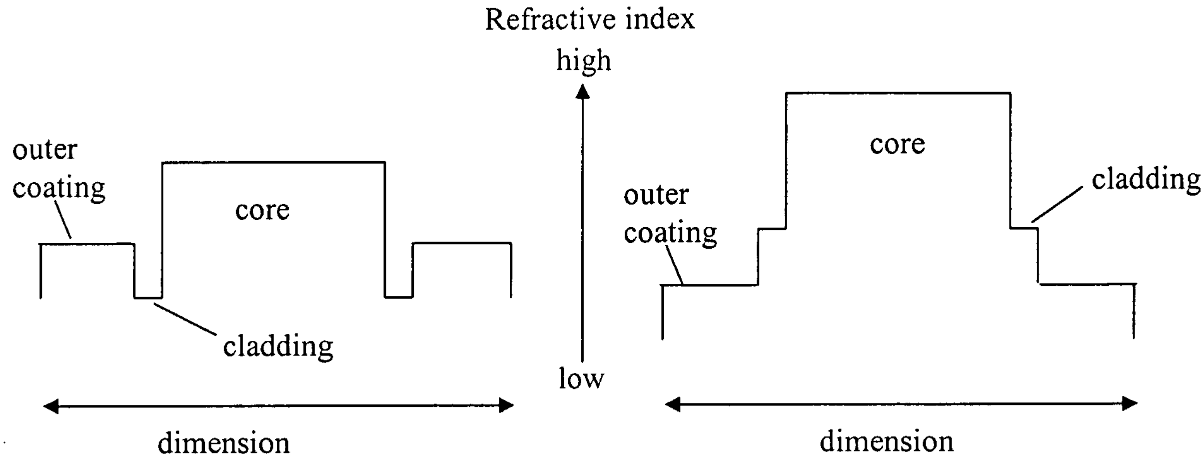


Fig. 3b Two types of fibers showing differences in core, cladding

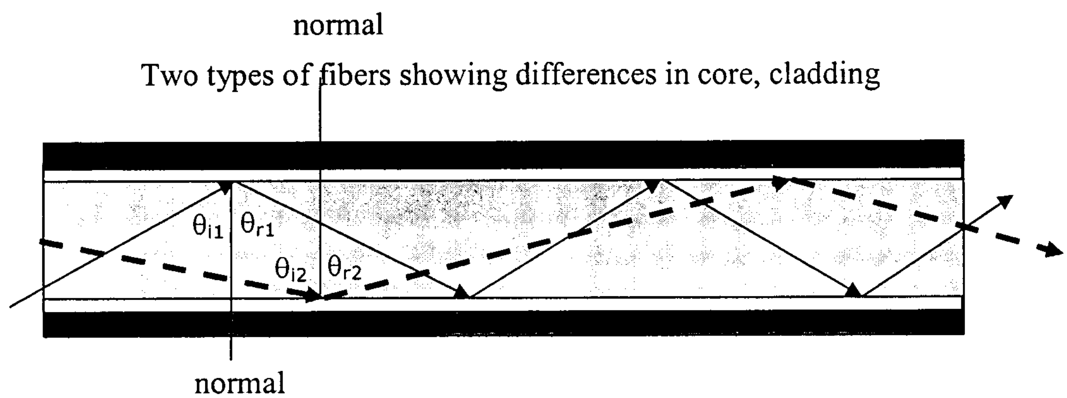


Fig. 3c. Beam transmits through optical fiber by total internal reflection.

Laser fiber and local modes

Fiber laser is just as other solid state lasers where pump energy is delivered into a gain medium that is doped with active species. Since it is difficult to inject enough energy into a fine core that is only a few or a few tens of micron, double cladding fiber is invented in which pump energy is delivered to the gain medium through total internal reflection. Fig. 4a shows a double cladding laser fiber that is similar in structure with the cross-section in Fig. 3a.

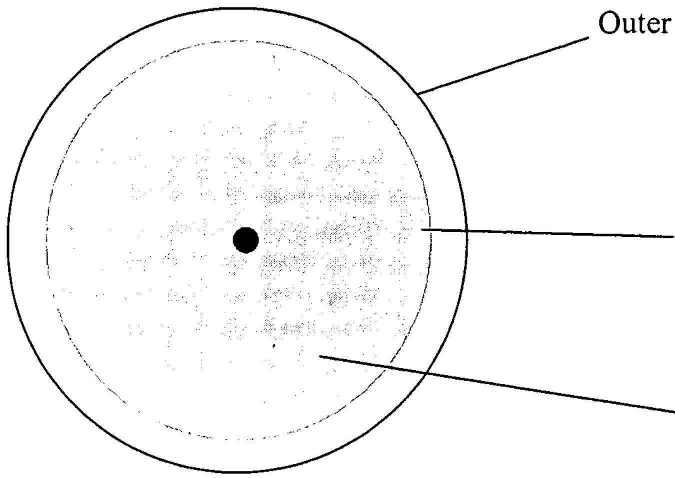


Fig. 4a Cross section of a typical double cladding laser fiber

A cladding-pumped fiber has a core which is doped with a rare earth (for example ytterbium). The core is surrounded by an inner cladding with a lower refractive index, so that the core can guide a signal beam propagating in the fiber. The inner cladding, in turn is surrounded by a lower-index material, the outer cladding. The outer cladding confines beams inside of inner cladding by total internal reflection. Thereby, the inner cladding becomes a waveguide, for pump light. Since the inner cladding is quite large, it is possible to launch large amounts of pump power into it from pump sources. Based on the law mentioned earlier, there will be no total internal reflection at the interface between the core and the inner cladding. As pump light propagates down the fiber, it crosses the core every now and then. It is then absorbed by the rare earth ions, which then become excited and generate gain for the signal beam in the core. Because the interaction between the pump beam and the rare earth doped core is relatively weak, cladding-pumped fibers can be quite long, up to ~100 m.

For high efficiency, it is desired that the energy can be efficiently absorbed by the core in a short distance. The outer cladding is normally made of low refractive index fluoro-polymer due to the limitation in material availability. This polymer laser often plays two roles, therefore: confining light and protecting the fiber. Sometimes extra coating is provided to

protect the outer cladding. It should be noted that, just as in the light transmission fiber, there is no light going through the cladding layer that is used for confining light.

Fig. 4b shows the refractive index of the components in a typical double cladding laser fiber. Fig. 4c shows the propagation of pumping beam in the inner cladding. When the beam passes through the core, part of the energy will be absorbed as pumping energy.

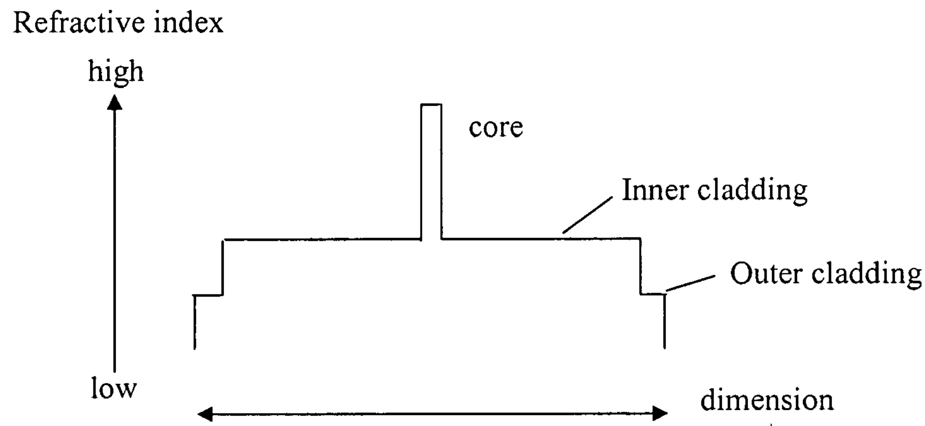


Fig. 4b Refractive indices of the components in a typical laser fiber

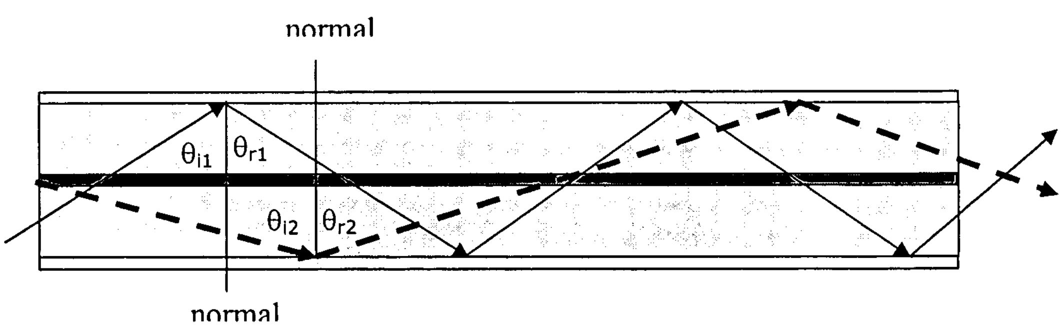
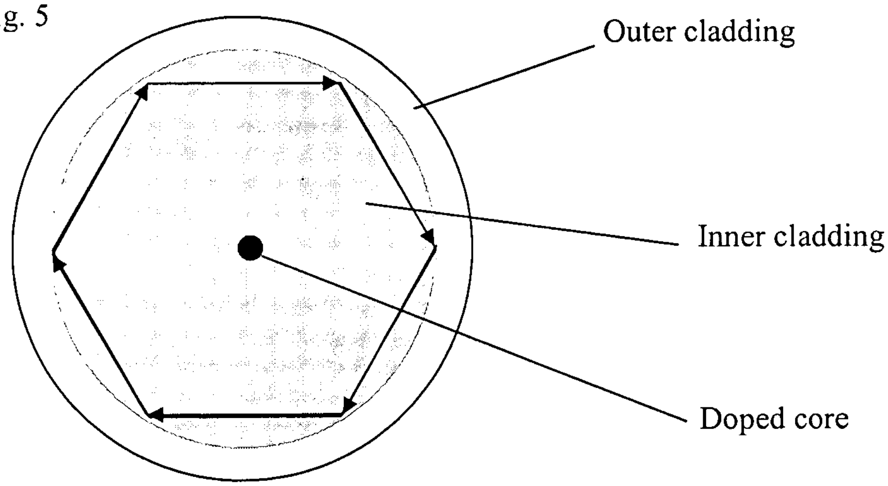


Fig. 4c Light propagate in a double cladding fiber

Due to the small size of the core comparing with the size of inner cladding, efficiency issue becomes a problem. This is particularly severe when high power device is desired where the size of inner cladding is further increase to accept more pump energy from the pumping source. This efficiency problem is mainly caused by the pump energy that could never reach the fiber core before it exits from the other end of the fiber. Those beams that are localized in the inner cladding without being able to pass through the fiber core are described being trapped in local modes. One example is the helical beam path (Fig. 5) in a fiber with circular inner cladding shown in Fig. 4a. In a fiber with a circular inner cladding and a centered core, there are large amounts of such localized beam paths, and a large fraction of the pump light never crosses the core.

Fig. 5



Cross section of a typical double cladding laser fiber with circular inner cladding configuration

The geometry of inner cladding and the current disclosure

As shown above, the geometry of the inner cladding is very important. Many efforts were made by various researchers to improve the inner cladding structure for better efficiency. Some of the improvements were made by careful analyses; while others were suggested without fully recognize the problem of local modes. We define local modes as the

beams inside of inner cladding that can never interact with the doped core and can never be absorbed. The serious the local modes, the lower the efficiency of a double cladding fiber will be.

Rejection Compared to Claims as Presently Amended

DiGiovanni (US 5,949,941) relates to cladding pumped fiber structures having index modulation within a substantially circular outer diameter useful for laser applications.

DiGiovanni's has a triple cladding structure as distinguished from applicants' double cladding structure. This triple cladding structure is based on the mode mixing of (1) the first inner cladding (see 34, Fig. 2) and (2) the second outer cladding (see 36 Fig. 2) wherein the index of refraction of the outer cladding is less than the index of refraction of the inner cladding. In the case of DiGiovanni, both the first inner cladding (34) and the second out cladding (36) transmit light. It will also be seen that DiGiovanni has a circular outer polymer layer (see 38, Fig. 2). This layer is to protect the outer cladding and prevent the loss of light from the outer cladding. An explanation of the interrelationship of these respective claddings is given at col. 3, line55-57, col. 4, line 41-45, and claim 1.

Specifically, it is stated in DiGiovanni:

> Applicants have discovered that a laser fiber may be fabricated with a circular outer cladding based on index modulation. Applicants have further discovered that a polarization-maintaining optical fiber may be fabricated for use in laser applications via a cladding-pumped fiber having stress-inducing regions within the cladding. (Column 3, lines 55-57)
>
> ...Thus, the refractive indices of the layers become progressively less moving from the core to the second cladding 36. For example, an inner cladding having a refractive index of approximately 1.45 (for pure silica), can be combined with a second cladding having a refractive index within the range of from 1.44 to 1.38. An outer polymer coating layer 38, preferably has an even lower refractive index, although

> this is not essential. The polymer coating 38 should not have a higher index of refraction as compared with the second cladding 36 for the most effective device, though it may be higher and still operable.
>
> Applicants have discovered that with this configuration, the first inner and second claddings cause mode mixing due to refractive index changes. Further, mode mixing occurs with relatively minor variations in the refractive indices between the inner cladding 34 and second cladding 36. (Column 4, lines 38 to 54)

Thus, DiGiovanni discloses a triple cladding fiber, comprising (1) a core fabricated with a rare-earth material having a predetermined refractive index; (2) an inner cladding surrounding the core having an asymmetrical outer circumference and a refractive index that is less than the refractive index of the core; (3) a second cladding surrounding the inner cladding having a substantially circular outer circumference and a refractive index that is less than the refractive index of the inner cladding and (4) the outer polymer layer.

Two of the claddings of DiGiovanni transmit light.

In applicants' disclosure, only the inner cladding transmits light. The outer cladding does not transmit light.

In DiGiovanni, the disclosed index modulation between the inner cladding and outer cladding causes distortion of light rays pumped into the fiber to direct the rays to the core.

DiGiovanni shows that with this configuration mode mixing of light can be accomplished between the inner cladding 34 and the outer cladding 36 through index modulation.

As an aside, DiGiovanni further shows a fiber configuration in which stress-inducing regions disposed within the inner cladding produce both ray distortion and birefringence to define a polarization-maintaining fiber useful for laser applications.

It should be noted that the functions of DiGiovanni's outer polymer layer and the outer cladding disclosed in the current application are the same: protecting the fiber and confining the beam inside of the inner cladding(s). However, that is where the similarity ends. Applicants' outer cladding functions to protect the inner cladding and to confine light within the inner cladding. Applicants' outer cladding does not transmit light.

In DiGiovanni's triple cladding fiber, both the inner cladding and the second cladding transmit light and are necessary to work together for achieving mode mixing. This joint-function of first and second claddings is described at col. 4, line 41-51. (see above)

This is to be contrasted with applicants double cladding fiber disclosed in the current application. Only the inner cladding transmits light to the inner core doped with active species in applicants' disclosure, not the inner cladding and the outer cladding.

Because DiGiovanni's invention is using both the inner cladding and the outer cladding to transmit light, and using index modulation, DiGiovanni does not teach or suggest how local modes can be reduced or eliminated. In fact no local modes or similar problems are mentioned in DiGiovanni.

Further, and in the discussion of Fig 3D, it is even believed that the cladding surrounding the core can be amorphous, without any clearly defined shape (col. 5, line 5-10). This is because of DiGiovanni's reliance upon index modulation between the inner (light transmitting) cladding and the outer (light transmitting) cladding. DiGiovanni discloses the fabrication method of similar fiber structure in US Patent 5,966,491. In this patent, the well-defined arcs as set forth herein, utilizing the fabrication process with flame simply cannot be achieved. It is well-known that in optical processing it is impossible to achieve a well-defined surface by (flame) ablation.

The most significant difference of DiGiovanni's inner cladding shape from the inner cladding shapes disclosed by the applicant is that the currently disclosed inner claddings are substantially non-circular as shown by the structure disclosed in Fig. 11a and 11b, while

DiGiovanni's inner claddings are substantially circular since he believes that it is unfavorable to have non-circular inner claddings (col.2 line 21-29), while such belief is incorrect because symmetric polygon inner cladding has been used for years. The skewed polygon inner cladding disclosed in the present invention will enhance the efficiency and minimize the loss that DiGiovanni saw in symmetric non-circular inner claddings (col. 2, line 24-25).

US Patent Application Publication US 2002/0172486 A1

In this publication filed on March 16, 2001, Fermann discloses polarization maintaining optical fibers, claiming cross sectional shape in the form of a distorted hexagon or a polygon with (2n-1) sides, where n>2. In fact, to make a polarization maintaining fiber, other measures must be taken such as using elliptical core or other features. Fermann's distorted polygon has been referred in the prior art; no introduction of arcs in such distorted polygon is suggested.

The Geometry of Inner Cladding and the Current Disclosure

As shown above, the geometry of the inner cladding is very important. Many efforts were made by various researchers to improve the inner cladding structure for better efficiency. Some of the improvements were made by careful analyses; while others were suggested without fully recognize the problem of local modes. We define local modes as the beams inside of inner cladding that can never interact with the doped core and can never be absorbed. The more serious the phenomenon of the local modes, the lower the efficiency of a double cladding fiber having those local modes will be.

The following are a list of patents and patent application publications as well as pending applications known to the applicant. Because there is a continuing need of a better and more efficient fiber, improvements are being made all the time. It is obvious that this topic is a crowded art.

U.S. Pat. No. 3,808,549, issued Apr. 30, 1974, to Mauer discloses a design in which a small, strongly absorbing, single-mode core is embedded in a large, multimode

waveguide. The fiber shown by Mauer was round with a concentric core as shown in Fig 5. This is a very inefficient shape for a double clad device. Because of the radial symmetry, many of the modes in the multimode waveguide do not interact with, and are not absorbed by, the concentric core. Improvements by Snitzer et al. (U.S. Pat. No. 3,729,690, Apr. 24, 1973 and U.S. Pat. No. 4,815,079, Mar. 21, 1989) included the use of an off-center, circular waveguide as well as a rectangular guide with two different transverse dimensions. (Fig. 6) The removal of local modes in these structures is very limited.

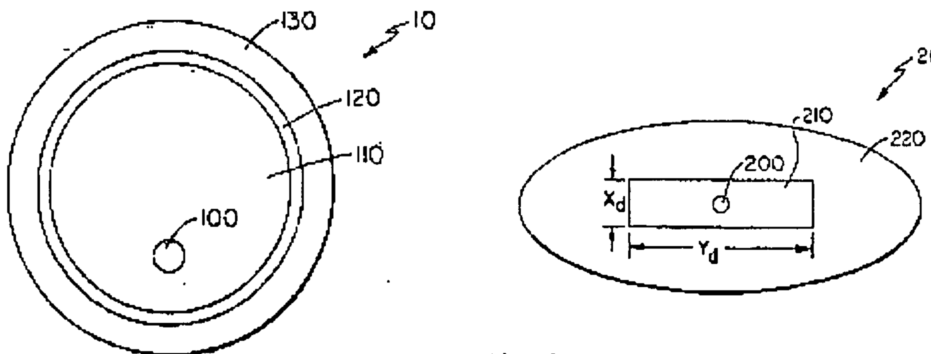
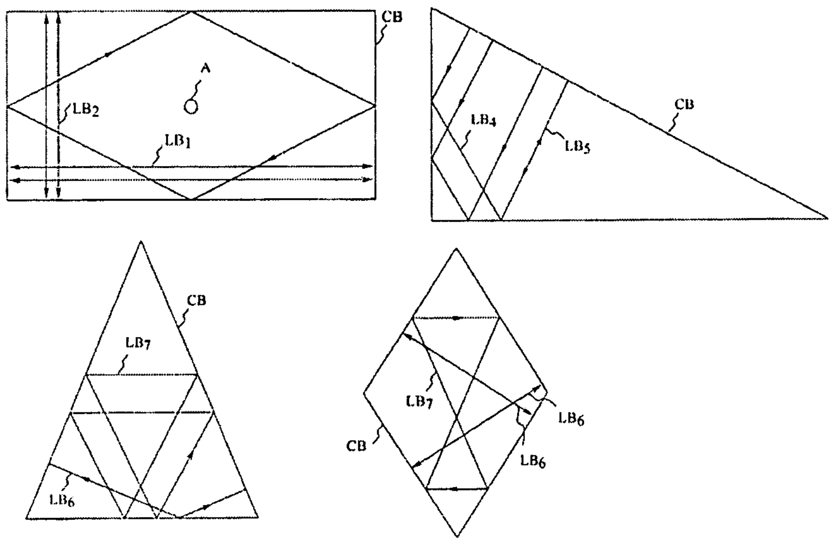


Fig. 6

Lewis et al., in U.S. Pat. No. 5,418,880, May 23, 1995 and Muendel, in U.S. Pat. No. 5,533,163, July 2, 1996, teaches the use of various space filling polygons. Such shapes are limited to triangles, certain symmetric quadrilaterals, and regular hexagons (Fig. 7a). Two criteria were set for the polygons Lewis and Muendel claimed: (i) if a number of identical polygons were used to cover a planar region by tiling, all of the polygons would fit into the tiling arrangement with no spaces present between adjacent polygons and (ii) all the polygons would be mirror images of one another about any common side. Lewis and Muendel emphasized the importance of "uniform radiation" when considering the inner cladding shapes, while "uniform radiation is not important as long as the beam can quickly interact with the doped core to deliver pump energy. Fig. 7b shows the local modes in some of structures proposed by Lewis and Muendel.



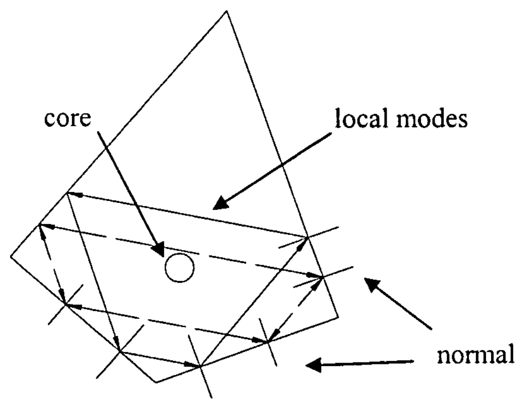
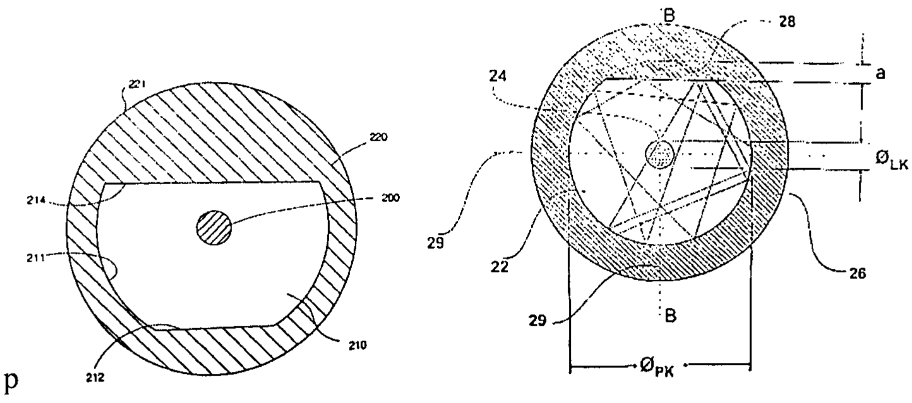


Fig. 7b

Zellmer et al (US Pat 5,864,645, Jan 26, 1999)teach inner cladding shapes constructed with a substantially circular cross section having at least one ground portion on the outside (Fig. 8a). Further modifications were disclosed by Grubb et al (US Pat. 6157,763, Dec. 5, 2000) (Fig. 8b) and by Po (US Pat. 6,516,124, Feb.4, 2003) (Fig. 8c). In Grubb's disclosure, the cross-sectional shape of the inner cladding is such that two perpendicular distances across the shape, each of which passes through a geometric center of a core of the fiber, are equal for all angular positions. In Po's disclosure, inner cladding has an outer perimeter that is substantially

Fig. 8a

circular except for two substantially flat sides. The two flat sides are substantially



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parallel or not parallel, and are substantially non perpendicular. Nevertheless, in all these structures, local modes can not be substantially eliminated and thus the efficiency is far from optimized. Some of the local modes present in a circular inner cladding still exist and some of the local modes in regular polygon also exist as shown by the thick arrows in Fig. 8a, 8b and 8c. Although Po discloses a plurality (185 claims) of various geometric shapes, including straight lines and arcs, which may or may not have asymmetric shapes, he does not teach how to remedy the local modes situation if it is encountered.

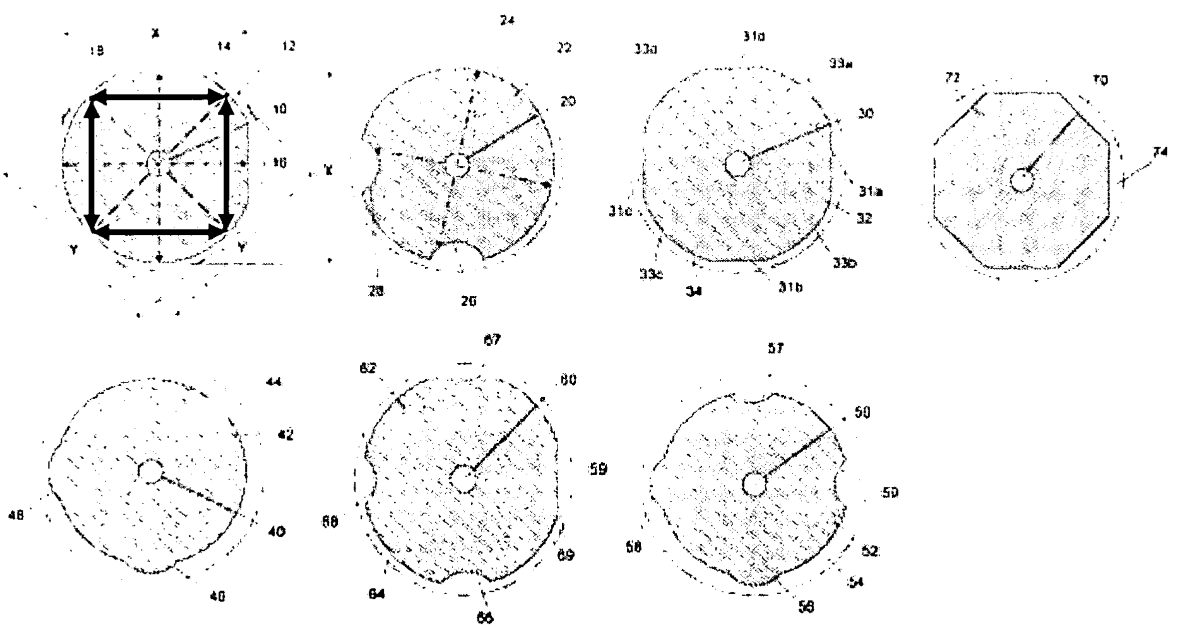


Fig. 8b

DiGiovanni et al (US Pat 5,949,941, Sept. 7, 1999, and US Pat. 5,966,491, Oct. 12, 1999) discloses polygon-like inner cladding in double and triple cladding fibers where the boundaries of the "polygon" are a group of arcs that have no definite shapes (Fig. 9a). Tankala et al. (US Pat 6,477,307, Nov. 5, 2002) discloses a series of straight line and convex curvilinear boundaries between the inner and outer cladding. While specific shapes are disclosed which may or may not have local modes, there is no systematic teaching of process for the elimination of local modes. Whenever a symmetric structure is used, local modes will occur according to the law of reflection, and thus lower the efficiency of the fiber. Two disclosed inner cladding shapes are shown in Fig. 9b with the local modes being exemplified in arrows.

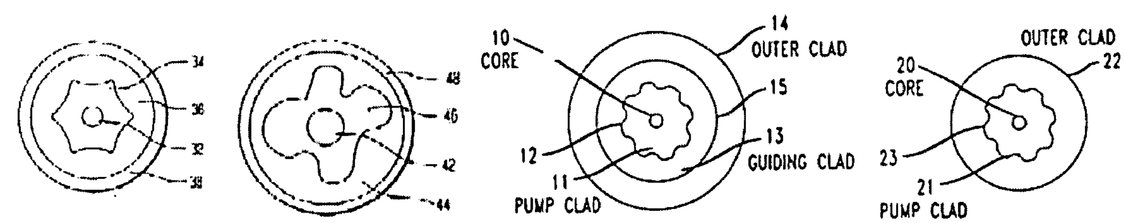


Fig. 9a

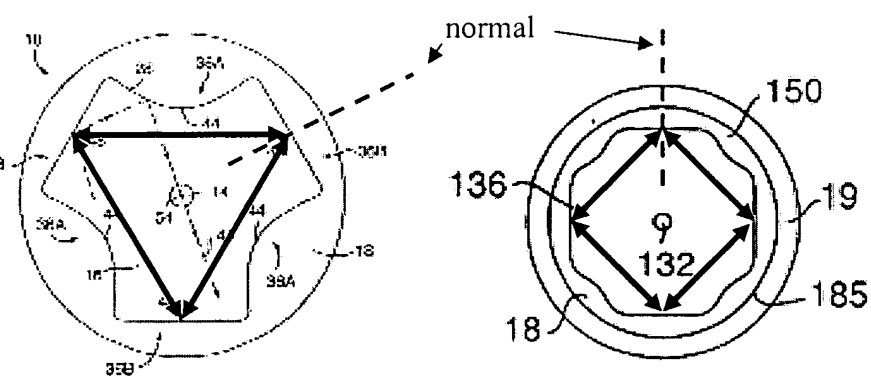


Fig. 9b

Another similar improvement is in the disclosure of Anthon et al in US Pat 6,411,762 (June 25, 2002), where a very difficult method was described to make double cladding fibers with inner cladding that has a plurality of irregularities formed at least along the outer boundary such that the outer boundary is radially constrained and quasi-circular. A few inner cladding shapes are shown in Fig. 10. The irregularities in the boundary are often undesired because the consistency

of fiber performance will be difficult to predict. In the situation of creating lobes along the outer boundary of inner cladding (such as 40 in Fig. 10) can remove some of the local modes just like some of the inner cladding shapes in Fig. 8b, but many local modes from a circular inner cladding shape will remain.

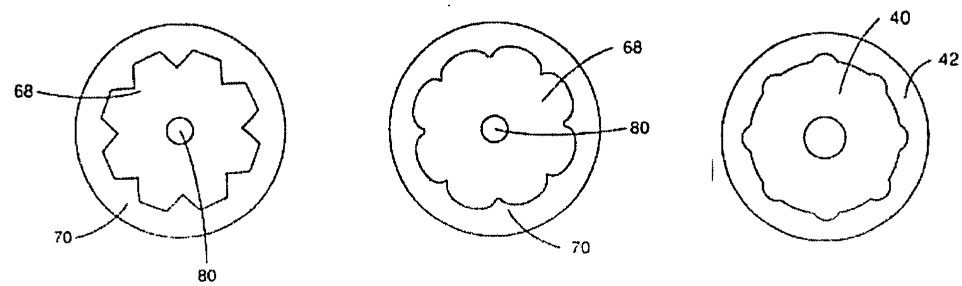


Fig. 10

The applicant discloses asymmetric and symmetry-broken polygon shapes in US Pat 6,101,199 (Aug. 8, 2000), such as the examples in Fig. 11.·By proposing introducing small angles into a regular polygon to form a skewed polygon, the local modes presented in a regular polygon can be reduced or eliminated. This invention is based on the law of reflection. The presence of small angle prevents any beam to be localized so that all the light can pass through the core and be absorbed.

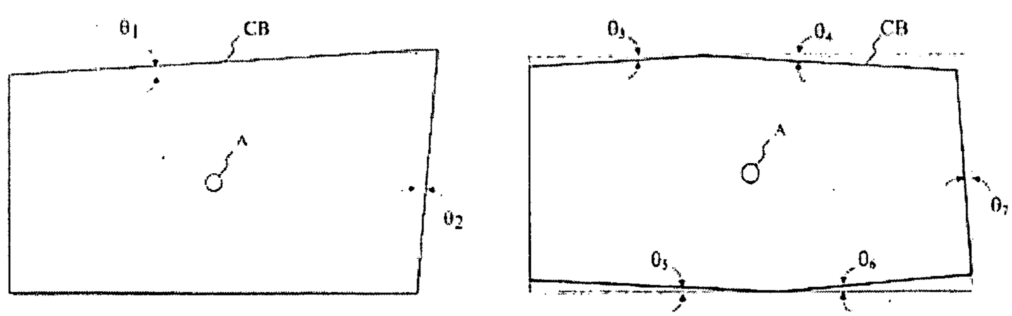


Fig. 11

These asymmetric and symmetry-broken structures are novel because they are not implied or taught in the prior art. They are also not obvious because over the years much attention has been left on the localized light reflecting within circular inner cladding while the local modes in a polygon have been overlooked. In other words, the reflection properties of light in inner cladding have not been fully recognized. On the other hand, skewed polygons are relatively easy to make since the introduction of a small angle can already make a big difference based on simple ray tracing using the law of reflection. To the skilled in the art, it can be seen that simple optical processing techniques can be used for the preparation of fiber performs.

This patent is currently under the processing of reissue application by the applicant.

In different pending application, the applicant also discloses a further improvement based on the law of reflection in structures similar to an unstable resonance cavity. The boundary of the cross-section shape of a inner cladding with respect to the outer cladding is formed with a plurality of arcs. Each of arcs has a well-defined radius from its arc center wherein any at least two opposite and non-adjacent arcs in the boundary of said cross-section shape satisfy certain unstable cavity conditions. An example is show in Fig. 12. Unlike any of the quasi-circular proposed in the past, no local mode can exist in such inner cladding. And unlike any of the inner cladding with irregular or undefined arc boundaries, the behavior of beam in these novel inner claddings is well defined because the arcs of the inner cladding boundary are well defined.

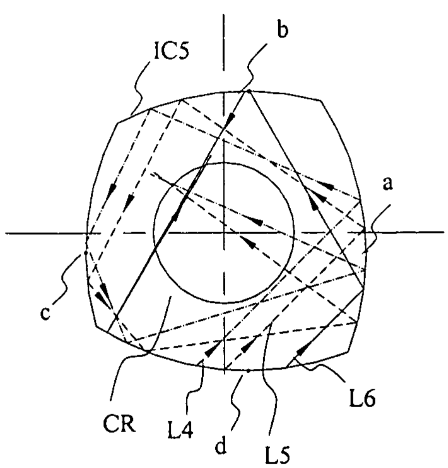
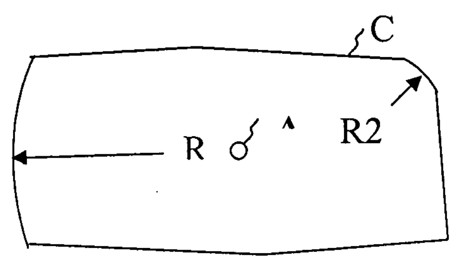


Fig. 12

The current application is an improvement based on US Pat 6,101,199 by the applicant. The applicant unexpectedly discovered during the research of inner cladding shapes disclosed in above mentioned patent that making the sharp corners round or leaving at least one edge of a skewed polygon boundary to be arc will not affect the effectiveness shown in the structures proposed in US Pat 6,101,199. One example is shown in Fig. 13.

Fig. 13



Based on the comparison at the beginning of this amendment, revised claims, the novelty and unobviousness of the current application are clear.

Conclusion

The current invention is an improvement based on US Pat. 6,101,199 (Aug. 8, 2000) (prior art for Fermann's publication.) It was a surprise to the applicant that by introducing arcs into the skewed polygon inner cladding while keeping the polygon characteristics as disclosed in this application, the efficiency of the fiber was not affected. The shapes disclosed are novel with respect to the two layer cladding construction. It is submitted that it is unobvious to those skilled in the art to have the combination of the skewed boundaries and arcs set forth. Although the citations supplied by the Examiner indicate that this is a crowded art, the specific claimed combination is not present. Allowance is urged.

CONCLUSION

In view of the foregoing, Applicants believe all claims now pending in this Application are in condition for allowance. The issuance of a formal Notice of Allowance at an early date is respectfully requested.

If the Examiner believes a telephone conference would expedite prosecution of this application, please telephone the undersigned at 415-576-0200.

Respectfully submitted,

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